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ABSTRACT

This article addresses what was learned through the National Computational Science Leadership Program about involving teachers in planning high quality units of instruction around computational science investigations. Two cohorts of roughly 25 teacher teams nationwide were given opportunities to develop "replacement units." The goal was to support high school teachers in incorporating computer modeling and the complex thinking that goes with it into their teaching. Teams received some initial training, then met throughout the school year to think about the unit they would develop. During the following summer, they met for an intensive, 2-week institute and received more training on software and one-on-one consultation with experts as they developed their units. At the end of the 2 weeks, they shared their unit design and materials with the group, and units were posted on a Web site. Teachers were expected to teach the units during the upcoming school year. This paper examines: unit planning approaches (standards-based units, backwards design units, project-based units, and problem-based learning units); development of a project planning tool; one project teacher's account; and project teachers' reactions to the planning and reflection tools. An appendix presents a computational science skills unit planning and reflection matrix, using a human population studies unit as an example. (Contains 16 references.) (SM)

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A Structured Professional Development Approach to Unit Study: The Experiences of 200 Teachers in a National Teacher Development Project

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A Structured Professional Development Approach to Unit Study: The Experiences of 200 Teachers in a National Teacher Development Project

Introduction

Research on the quality of assignments (e.g., degree of cognitive challenge) that teachers provide students (Clare & Aschbacher, 2001; Newmann, Bryk, & Nagaoka, 2001) suggests a relationship between the quality of thinking and work students are asked to do and their achievement levels. Logic would also suggest that students who experience more opportunities to apply critical thinking (e.g., engage in meaningful scientific investigations) would be able to demonstrate those skills to a higher degree than students who do not have such opportunities. In other words, the quality of learning experiences provided students matter. This article addresses what we have learned from the National Computational Science Leadership Program (NCSLP) about how to involve teachers in planning high quality units of instruction around computational science investigations. We use the term "unit" to describe a flexible but bounded grouping of educational experiences designed to develop specific content knowledge or skills in students. In other words, we are focusing on how the students experience the unit as a whole, not just the unit as the particular topic covered (e.g., a unit on electric circuits).

Lesson study as it occurs in Japan represents a process for the continuous improvement of the quality of learning experiences provided through lessons. It is an example of a structured professional development program built around teacher participation in study groups that collaboratively plan, implement, evaluate, and revise lessons (Hiebert, Gallimore, & Stigler, 2002). The ultimate product is high quality lessons that can be replicated from year to year and by other teachers.

Whereas lesson study in Japan seems from the descriptive accounts to be institutionalized in terms of norms, tools, processes, etc., approaches to involving teachers in unit development and refinement in this country often happen outside the working environments of teachers (schools and districts). That is, there are some national, state, or university projects funded to involve teachers in unit design but the reports on these projects are somewhat scattered. It is important to begin to reflect on the experiences of these projects because they have implications for how schools and districts might begin to think about institutionalizing similar kinds of professional development for teachers.

The context for this paper is the National Computational Science Leadership Program (NCSLP), an NSF funded institute that was designed to provide two cohorts (100 per cohort) of roughly 25 teacher teams from across the country opportunities to develop "replacement units". The goal of the program was to support high school teachers in incorporating computer modeling and the complex thinking that goes with it into their teaching. This account represents a collaboration of the NCSLP project Co-PI, the project evaluator, and a project teacher. It describes some of the challenges and processes used in providing structure to the teachers engaged in planning, implementing,

and revising their "replacement units". It provides insights into the scaffolding and supports needed if teachers are going to be successful with improving the quality of learning opportunities through unit redesign.

Project Design Factors

Discipline-based professional development projects that have as their goal the integration of new technology, deeper levels of content understanding, or inquiry-based teaching methods into teaching must determine how they will engage teachers in making changes to the current segmentation/organization of their course. Below we discuss several factors that seem important in the design of professional development that has as its goal improved teaching methods.

1) *Role of the teacher*. Some projects develop "teacher-proof" curriculum materials that do all the organizing and development for teachers and in some cases even lay out a day-by-day schedule for the whole year. There are some advantages to this approach for teachers who have very little experience in the subject area and can benefit from having the daily lesson plans for the year outlined for them. Other projects, perhaps more relevant for teachers with more extensive content knowledge and experience, involve teachers in developing a unit or sequenced set of instructional materials.

2) *End product*. For projects that involve teachers as curriculum developers, an end result may be that participating teachers post their units for others to use (NCSLP). Other projects may treat teachers as co-authors but the units are further developed to a higher level by project staff with content expertise; as a result, there is a longer product testing period before they are made available. How to best present units for others' use is another design factor that project organizers need to consider. If a unit is intended as an organic, integrated whole rather than as a collection of lessons, activities, and resources that are connected by a unifying concept or topic, then somehow the importance of the particular logical ordering and sequencing of instructional events needs to be communicated. Static unit descriptions (objectives, lessons, assessments) may not communicate the interrelationships of the sequencing.

3) *Structure of professional development*. Projects that engage teachers as primary unit developers or co-developers are time intensive. They are even more time consuming if they include helping teachers through the implementation and reflection process (after the unit is developed). It seems that teachers are provided very little time and support for unit planning. Rather the nature of the time scheduled into the school day (30-60 minutes per day) probably encourages a next day or single day approach to planning. Thus, opportunities to plan units within a team setting with sufficient time allowed for in-depth work (as in during the summer) will likely have to come from district, state, or national initiatives. To the extent that content and pedagogy experts are available as supports to teachers to help them in their planning of units, the professional development experience becomes perhaps even more valuable.

4) *Evaluation of unit quality.* Even beyond initial piloting of the units by teachers, project designers must consider how the quality of the units of the units will be judged both by the individual teacher and by the project staff. The approaches taken may range from self-assessment (teacher's use of a rubric that describes dimensions of quality) to the use of a peer group who may use a "tuning" or other protocol to provide feedback. There is also some evidence (Wilson and Sloane, 2000) that involving teachers in examining and judging student work samples on important performance tasks and providing opportunities for them to discuss the implications of the student scores for future instruction leads to significant differences in student achievement when compared to teachers who did not have these structured opportunities to discuss the quality of student work produced.

5) *Impact on school curriculum.* Those undertaking to support teachers in unit development vary in terms of the degree to which they have in mind the school context. For example, one project may focus solely on individual teachers with no focus on the larger curriculum context at the school. Another may have in mind a domino effect such that providing one or two teachers the opportunity to develop a particular kind of unit may produce an "exemplar" unit for process skills that need to be taught school-wide. Project designers may differ in whether their ultimate end goal is the entire school or the individual teacher.

These project design factors provide a framework for describing particular professional development projects. The NSF-funded project described in this article involved a national cohort of teachers in developing and piloting "replacement units" with the goal of making these units available to other teachers. Project designers had learned from previous experiences with teachers that this kind of sophisticated integration of technology happens most productively in collaborative, cross-disciplinary teams. Applications were solicited from schools interested in sending a team to participate with the understanding that they would be committing to developing and implementing a "replacement unit" (replacing a unit they currently taught with a new one which would incorporate computational science thinking). Thus, teachers would play the role of curriculum developer. The "replacement units" were to be made available on the project website (www.ncsec.org).

The structure of the professional development was such that the teachers came together for a week-long fall kick off taught by a "faculty" of computational science experts. The teams were expected to continue meeting and thinking about the unit they would develop during the school year. During the following summer, teams came together for an intensive, residential two-week institute during which time they were offered more training on software and one-on-one consultation with experts as they developed their units. At the end of the two-week institute, each team shared their unit design and materials with the whole group and the units were posted on the project website. Teachers were expected to teach the units during the upcoming school year but there was no project structure to support this. In fact, not all the teams actually taught their replacement units. There were no systematic efforts to involve the first cohort of teachers in looking at the quality of the units. In their week-long fall kick-off, the

second cohort of teachers were asked to review the first cohort's units and thus, by the nature of the questions asked, had a better sense of the dimensions of quality units.

Some teachers came from schools with highly experienced science departments who had been committed for several years to incorporate computational science methods into the curriculum. One teacher, when asked, given his experience level, why he chose to participate in yet another professional development experience, answered that the time and support for rethinking instructional units was just not available in the regular school setting. The project's offer of three weeks of supported professional development in building a "replacement unit" was a unique opportunity. Other teachers came from school settings with little ongoing, systematic curriculum revision work going on in science and came more for the opportunity to learn about computational science methods and software (with less commitment to the replacement unit idea). In those schools interested in infusing more computational science into all their science courses, participation had the potential for a greater impact on the school curriculum.

Understanding Unit Planning Approaches

When an organization (national, state, district, or school) decides that it is important to involve teachers in unit development or redesign as part of a professional development effort, they need to understand the different approaches to planning that teachers may bring with them. They need to understand the similarities and differences between various approaches to planning that are in vogue, and, thus, could be referenced by teachers. Although not intended as exhaustive, it is informative to examine several types of unit design referenced in the literature.

Standards-Based Units: Focus on State or District Standards

Standards-based planning, as a term, emerged in the 1990s with the emphasis on teaching to state and district standards. Standards are a slightly new twist on the more traditional educator language of instructional goals and objectives. The new twist to renaming instructional goals and objectives as standards is that they now carry an intent to monitor (are students meeting them and how will states know?) and an intent for more "standardization" of what is taught. The advantages and disadvantages of state efforts to articulate standards and then monitor results (assess achievement) are still being debated, yet standards are to a great extent in teachers' minds when they plan.

According to Solomon, (2000), in typical unit planning…

"Choices of activities are usually loosely connected to the content standards but are frequently based on other criteria, such as accessibility, student control and interest factors, and public relations appeal. For example, worksheets are easy to obtain and use; they control children and document and advertise the curriculum to a parent".

In contrast, Jamentz (2002) describes the steps involved in standards-based planning as:

- Select standards from among those that students need to meet
- Design an assessment through which students will have the opportunity to demonstrate the knowledge and skills involved in the standards
- Decide what learning opportunities students will need to learn those things
- Plan instruction to ensure all students have adequate opportunities to learn
- Use assessment data to give feedback, reteach, or move to the next level

Solomon argues that designing a whole curriculum from the graduation standards to individual lessons is a monumental task. Instead, Solomon has worked with teachers by beginning with the redesign of a familiar two-week unit (www.stac.edu/mcc/indexrev.htm). The professional development process is similar to that used by others (teachers worked in teams or pairs during the summer, college faculty were involved as parallel unit developers and as resources for teacher teams, held small group meetings in the fall as teachers piloted their units).

Backwards Design Units: Focus on Enduring Ideas

A Backwards Design unit begins by focusing on and orienting students to the learning outcomes of the unit. In fact, Wiggins and McTighe (1998, p. 117) emphasize this necessity :"Early in a unit, we must orient students to the purposes and obligations that are most relevant to final assessments of their understanding." The authors recommend that teachers should select "big ideas having enduring value beyond the classroom" as the central theme of the unit.

An acronym used by Wiggins and McTighe (1998, p. 115-116) to describe the sequence of activities in a Backwards Design unit is "WHERE." The key component parts of the unit, then, include:

a) **W**here are we headed? As stated previously, unit designers first focus on desired learning outcomes.
b) **H**ook: The hook should "entice or provoke" students. Using questions, problems, puzzles, role-play and dilemmas are all examples of ways to hook students.
c) **E**xplore and Enable or Equip: In this stage of the unit, activities are designed to help students "dig deeper and go broader to make sense of things" and "learn needed facts, examine relevant theories, find and explore resources, and develop needed skills" (p. 123).
d) **R**eflect and Rethink: These activities are important, if students are to form deep understanding of content, as "The likelihood of a more sophisticated

understanding depends on enticing and requiring the student to constantly use and rethink her concepts, points of view, and theories..." (p. 125).

e) Exhibit and Evaluate: In this final unit phase, students are encouraged to present their knowledge through the use of "authentic products and performances that involve a meaningful context, clear purpose, and audience" (p. 126). These products and performances can then be judged for quality and effectiveness using the criteria originally constructed by the unit designer.

In the Backwards Design unit, the design of the assessments precedes instructional design, as the major assessment tasks imply the teaching that must be done for tasks to be accomplished and for learning to be coherent. The focus of assessment in this type of unit is to ascertain the quality and depth of student understandings.

Project-Based Units: Focus on Student Ownership and Personal Meaning

The project-based learning approach aids teachers in encouraging students to interact with people, objects and their environment in "ways that have personal meaning to them" (Katz & Chard, 1992, p. 3). The underlying principle of project-based learning appears to be the belief that knowledge acquired through such meaningful interactions is more likely to be remembered. Katz and Chard (1992, p. 20) state that for students, "workbooks and drill sheets are not purposeful enough for applying skills. Not only do such learning aids usually fail to engage children's minds, but they may also prevent children from understanding the purpose and use of skills."

However, by providing meaningful activities within the context of a project, students learn relevant content and build relationships between ideas that enable them to apply the learned knowledge in other contexts (Kanter, Kemp & Reiser, 2001). While teaching students new knowledge is certainly the main learning goal of a Project-Based unit, other learning goals involve skills, dispositions and feelings. Project work can also help a child feel important and included in the life of the classroom (Katz & Chard, 1992).

There is no particular, concrete set of steps to follow in a Project-Based unit (Blumenfeld, Krajcik, Marx, & Soloway, 1994). Rather, authors tend to speak in terms of project phases (Katz & Chard, 1992) or spirals (Kanter, Kemp & Reiser, 2001). The first stage, however, is always choosing a topic. In line with the underlying principles of project-based learning, this topic should take into account the "information, ideas, and experiences the children already have about the topic" (Katz & Chard, 1992, p. 82). In other words, project designers must consider the prior knowledge of the students when choosing the central theme for student work.

Subsequent stages in the Project-Based unit are designed to a) introduce new information to students and b) help students summarize their learning within the context of the project. Within the 'new information' stage, students may learn new skills, use investigative and/or technological tools, construct models, participate in role-play and

collaborate with others (Katz & Chard, 1992; Kanter, Kemp & Reiser, 2001; Blumenfeld et al., 1994; Krajcik et al., 1994). During the last stage of a Project-Based unit, students reflect on their learning, reach conclusions, create artifacts and sometimes present their work to audiences.

Problem-Based Learning Unit: Focus on a Contextualized Problem

Ill-defined, ambiguous problems are at the center of Problem-Based Learning (PBL) units. Such problems are complex, multi-faceted, have missing details and no known solution path (Butler, 1999). By working through the problem, students make connections between school and real life and between academic disciplines. Learning in this manner, by integrating content knowledge from several sources, fosters deep understanding of a topic, as the individual is able to meaningfully connect individual pieces of content (Torp & Sage, 1998).

Proponents of PBL units assume "that learning involves both *knowing* and *doing*. Knowledge and the ability to use that knowledge are of equal importance" (Bridges & Hallinger, 1995, p. 5). To this end, designers of PBL units choose problems that provide authentic experiences for students. Such problems may be ones that students are apt to face in the future or ones that are at least similar in context to problems students will encounter in their planned careers.

In a Problem-Based Learning unit, learning occurs mostly within small groups. The following stages occur as groups work through problems:

Meet the Problem: In this stage, students are confronted with a problem, which may be in any format -- a document, a dramatic presentation, a video, a presentation from a guest speaker.

Separation of Known Facts from Needed Knowledge: In this stage, students often make lists entitled "Know" and "Need to Know." The "Know" list contains facts garnered from the Meet the Problem stage, while the "Need to Know" list contains questions students feel must be answered before a problem solution can be found.

Definition of the Problem: Here, students work together to write a problem statement that articulates and summarizes the group view of the problem. The problem statement will serve as the blueprint for future work on the problem.

Research: Questions from the "Need to Know" list are researched, either by the group as a whole or by individuals who then bring their research results back to the group.

Information Exchange: Group members come together to share research results, perhaps formulate new "Need to Know" questions and construct new research plans. As mentioned previously, the "steps" of PBL can be iterative and it is up to the group to decide how many cycles of formulating "Need to Know" questions-research-sharing results are necessary.

Generation and Evaluation of Solutions: Groups may generate more than one solution, in which case they must discuss and evaluate each possible solution to the problem and then either pick the best proposed solution or formulate a consensual one composed of the parts from several alternative solutions proposed to the group.

Presentation of the Solution to an Audience: The formats for such presentations are as varied as the formats for the Meet the Problem stage.

Debriefing the PBL Process: In this stage, the instructor usually facilitates a large group discussion of the challenges and triumphs experienced by the students during the PBL unit.

Within a Problem-Based Learning unit, embedded assessments help provide teachers with a sense of students' thinking processes at various points within the study of the problem. For example, teachers can access the "Know" and "Need to Know" lists of students, written problem statements, summaries of research including logs, journals and progress reports, and data pertinent to solution generation as predictions, letters, diagrams and position papers. The presentation of the solution to an audience also engenders products accessible to the teacher, as videos, white papers, computer-generated multimedia presentations, etc. (Butler, 1999).

So How Do Teachers Really Plan?

The descriptions above represent various approaches to planning units that teachers might use given different instructional purposes. For example, backwards design might be helpful for topics in which the amount of content to be learned is overwhelming and the teacher is unclear where to focus instructional time. Project-based learning might be helpful in situations in which the thinking skills are perhaps more important than the particular content so that student choice about projects can be encouraged. Problem-based learning might be appropriate when there is a relevant and accessible real-world problem likely to generate student interest and engagement that can be used as a structure for a unit.

To what degree are these approaches represented in what teachers actually do when they plan a unit? There is very little research on how teachers plan units. The data we collected from participants in the NCSLP program helps with understanding the range of approaches teachers use.

Sixty-nine of the second cohort of teachers completed a questionnaire on their unit planning approaches during the 2002 summer institute. They were asked to respond to the following prompt: "If you were asked to teach a new topic within your content area, describe the planning steps you would take."

There were a few teachers whose responses could be categorized as lesson planning rather than unit planning. Three sample teacher responses are shown below.

▪ Locate resources ▪ Study and prepare lessons ▪ Present lessons ▪ Refine lessons based on student assessment	▪ See where it fits in my current curriculum ▪ Adjust time ▪ Decide how I will assess students ▪ Write lesson plans ▪ Teach	▪ Research the Standard Course of Study ▪ Find materials and references ▪ Make sure I completely understand the topic ▪ Write a lesson plan ▪ Teach it

Teachers' descriptions of their unit planning steps were sorted into five categories that emerged from the data. More specifically,

- 20 teachers articulated what was categorized as a content or topic-based approach
- 18 teachers described what was categorized as an activity-based approach
- 16 teachers described what was categorized as an objectives-based approach
- 7 teachers described what was categorized as an assessment-based approach
- 1 teacher was categorized as using a technology-based approach

The table below shows two selected sample teacher responses for each category used. (Only one is shown for the technology-based approach because only one response fit this category.)

Sample Responses to Identification of Planning Steps in Teaching a New Unit

Content or Topic Based	Activity Based	Standards or Objectives Based	Assessment Based	Technology Based
Define topic. Research topic. Break down topic into major sections. Draw up notes for each section. Plan activity or lab for each section. Specify days for each activity. Devise plan for assessment.	Check state standards for % of time to spend on topic. See how text covers topic. Devise experiments and activities to cover unit. Find internet resources. Develop timeline for unit. Develop lesson plans. Implement unit. Assess unit.	Check standards. Outline key objectives for unit. Decide how objectives will be assessed. Develop 1-2 interactive labs. Add in other activities/practice of key concepts. Unit exam.	Research the topic and collect materials. Develop end of unit project (not a test). Identify major topics/standards. Develop a timeline for topics. Plan labs, handouts, etc. See where intermediate assessments fit in (lab write-ups, journals, quizzes). Identify where technology could be integrated. On first day – introduce project and collect prior knowledge.	Review district and state standards. Consider current events. Determine possible ways to use computer technology to present topic. Determine possible ways to engineer a physical model to provide hands-on manipulation. Research for introductory material and vocabulary. Develop assessment tools (worksheets, physical models, computer animations, written reports, etc.). Review steps above and determine time for unit. Develop plans.
Research topic. Outline topic. Write notes. Gather or create activities. Plan lab. Plan assessment.	Brush up on topic. Get ideas on how to teach. Create schedule of events. Get specifics on how to do activities. Gather materials. Teach. Assess.	Determine what the outcomes should be. Look at what other teachers have done and consult with them. Determine how to assess prior knowledge. Develop the objectives. Develop teaching strategies to meet the objectives. Develop assessment tools to match the outcomes.	Look for ties to society/life. Narrow focus. Sketch a "centerpiece activity". Define content and skills that will be addressed. Evaluate the rough outline or direction for feasibility, logic. Develop timeline and flesh out other work as part of a logical progression. Make lessons.	

In summary, those teachers whose planning fell into the content-based category started their planning by thinking about the logical components of or concepts embedded in the topic (through an expanded outline, a teacher-developed concept map shared with students, list of "big ideas", ideas from students on what questions they had, looking for ties to society/life, etc.).

Those in the activity-based category described proceeding directly to finding ideas for instructional strategies (activities from text, internet, other teachers, etc.). These responses were likely to start with "research the topic" or "talk to other teachers about what they have done" but the structure for building the unit was around the kinds of existing activities that they located. That is, "finding activities" was a starting point.

Those in the standards-based category described organizing the topic by objectives and matching activities or lessons or assessments to objectives. The main difference between these responses and those in the activity-based category were that the teachers more explicitly seemed to organize the finding of activities around particular standards or objectives. Thus, steps included outlining objectives and then matching activities to objectives rather than just finding activities.

Those in the assessment-based category described planning the unit with the "operationalized" end in mind for students (the kinds of tests to be given or the kinds of work students would be asked to do). This is similar to the approach defined by Wiggins and McTighe (1998).

Interestingly, given that these project teachers were leaders in or at least very interested in technology, there was only one teacher who outlined a specific approach to incorporating computer models into the planning process as shown in the far right column.

Overall, the steps teachers described, although having somewhat different starting points, suggest that for many teachers, a unit is a loose collection of instructional activities on a topic. That is, they seem more accustomed to gathering instructional resources than designing a coherent, logical sequence that could be documented and repeated by other teachers.

Developing a Project Planning Tool

One issue faced by the NCSLP project planners was that the type of "replacement unit" desired from teachers was a fairly specialized type of unit. That is, although the project was described as an effort to engage teachers in developing "replacement units" which incorporated computational science modeling processes, the meaning of computational science was not clearly understood by some in the first cadre of teachers.

Brown and Edelson (2002) report a similar issue in their work with teachers on the co-development of an integrated curricular unit on global warming (http://www.letus.org/curricula.htm). They suggest that among the most common kinds of instructional discourse in secondary classrooms is the traditional lab experiment in which students "engage in prescribed tasks involving controlled variables, measurement tools, and data collection in order to observe or deduce some scientifically explainable event". Such labs typically focus on isolated scientific phenomena presented in an "easily digestible" format. The benefits of the use of labs are that they "help students sharpen their investigation skills, facilitate understanding of the scientific method, and make difficult to comprehend events visible within a straightforward setting that allows novices to interact with scientific ideas " (p. 1). Labs as instructional strategies also provide opportunities for students to work together.

However, labs are traditionally short, decontextualized instructional events that may not be well-suited to understanding certain abstract, large-scale phenomena like global climate change which involve interactions of many variables (e.g., solar energy, carbon emissions, surface temperature, surface characteristics, and human population). "These concepts and the relationships among them are difficult to comprehend with conventional lab tools. In the absence of a means to explore the global datasets required for such investigations, the potential scope and scale of scientific inquiry is significantly narrowed" (p. 2, Brown & Edelson, 2002).

In this project, follow-up interviews with the first cadre of teachers after the completion of their "replacement units" helped to identify some challenges faced when incorporating computational modeling investigations into the curriculum. Analysis of the units produced by these teachers showed that quality varied. Some units offered a logical, sequenced set of instructional and assessment activities organized around the investigation of a problem. Others focused more on the teaching of the topic (concepts) and included a computational modeling exercise as a teaching tool with minimal sustained involvement of students. Although both may be appropriate for different purposes, if the desire is to help students develop or gain experience with investigative skills using modeling software, the project goal of the replacement unit as a complex investigation needs to be fully articulated.

The project staff worked closely with one teacher (Erin Furtak) from the first cadre as a test case for trying to develop an exemplar for unit planning to make it easier for teachers to design units around a complex investigation. Through a group process of reflection (including the project evaluator, the teacher, a scientist, and a teacher educator) on her teaching of the unit, she was able to outline the unit in terms of a sequenced set of computational modeling skills. The sequenced set of skills makes it clear as to how the hypothesis-experiment-modeling paradigm (computer modeling as extended student investigation of real-world problems) differs from a more traditional hypothesis-experiment paradigm (the typical high school lab activity).

The sequenced set of expectations for students were:

1. Explore real-world problem
2. Develop background skills and knowledge
    - Conduct background research
    - Develop content understanding of key variables
    - Conduct labs to gather data if needed
    - Learn to use a modeling tool
3. Simplify the problem
    - Explain assumptions
4. Identify variables and interrelationships
    - Use appropriate tool to portray working model
5. Defend the identified relationships and assumptions
6. Represent relationships in terms of mathematical equations
7. Represent variables and relationships in a mathematical model
    - Discuss math equations
    - Translate the math model into a computational model
    - Run the model (simulate the problem)
    - Get results
    - Explore range of validity
    - Run check
8. Interpret findings
    - Evaluate results
    - Draw conclusions
    - Make recommendations
    - Interpret if the model agrees with observations
    - Revise working model or, if satisfied, proceed
9. Communicate findings

Clearly, from looking at this list, integrating computational modeling investigations into a course of study is no simple task. In anticipation of work with the second cadre of teachers, the project staff realized that simply showing the teachers a sequenced set of student skills would not provide enough guidance. The student skills needed to be shown "in action" with their associated instructional activities, probing questions, assessment methods, and types of feedback. Thus, using the experience gained from the implementation of her replacement unit, Erin completed a Computational Skills Unit Planning and Reflection Matrix (Appendix A). This "exemplar" unit was shared with the second cadre of teachers at the beginning of their two-week summer institute (during which time they would develop their "replacement unit"). In the next section, Erin shares her reflections.

One NCSLP Project Teacher's Account (Erin Furtak)

In my teacher education program, I was exposed to a traditional process of unit design. The process began by deciding upon a topic or concept to teach based upon state

standards, collecting resources, labs, and activities, and then selecting those that would most effectively teach the concept. The labs and activities were sequenced based upon my understanding of how the concept would be built in students' minds. In my science methods course, I learned to design assessments first, and then use them as a framework for activities, similar to the 'Backwards Design' principle proposed by Wiggins and McTighe (1998). However, the process of collecting, selecting, and sequencing activities was similar to the way I had done it before. While teaching, I moved away from the process of working "with the end in mind," and more often used lessons I had designed or that were shared with me by other teachers. This method of planning units was very similar to that used by other teachers at my school.

As a participant in Cadre 1 of the National Computational Science Leadership Program, I worked with three other teachers from Wheat Ridge High School to develop the computational science replacement unit, "Human Population Studies." As I planned the Biology strand of this integrated science and mathematics unit, I struggled to assemble lessons and activities that built both content understanding as well as computational science process skills. Furthermore, I was motivated to pique students' interest in computational science and population dynamics. I decided to develop the unit by posing a central problem to students, and then sequenced activities so that students could gradually develop content understanding around this problem through laboratory exercises, computational models, and research. Students involved with the unit would answer the question, "What does a human population need to survive?" This question was researched from a variety of perspectives, ending with students designing population growth models based upon data from different countries, and making recommendations to governments on how to control population growth.

After completing the unit, I realized that I had created lessons that would not have looked the same without the central problem and computational science as a tool to search for the solution. While students using traditional paper-and-pencil activities could have calculated shifts in population growth, the dynamic nature of computational models allowed my students to interact with birth rates, environmental factors such as pollution, and societal factors such as religion. The interactions of these variables with each other gave students a heightened understanding of the feedback systems involved in biological systems, as well as a deeper understanding of the math underlying population dynamics. The technology, therefore, was able to make a real difference in the depth of learning for my students.

After my experience as a Cadre 1 teacher, I continued to work with project staff to develop a method to help Cadre 2 teachers design more coherent and effective computational science units. The result of this collaboration (with vital input from Dick Allen) was the instructional planning matrix (Appendix A). The matrix integrated both the process a scientist goes through in building a model, as well as steps essential to teachers and students in building content background. The instructional matrix articulated a sequencing of activities that was new to me. Centered on a real-world problem to be investigated with a computational model, the instructional matrix made objectives clear and authentic to the learners.

I worked extensively with the instructional planning matrix after teaching the "Human Population Studies" unit to my 10th grade Biology students. I found that the descriptors fit my conception of how students used computational science to build deep content understanding, and also was able to identify areas that would benefit from revision in future teaching of the unit. Furthermore, I found that the matrix helped to organize my thoughts on unit design in general, and how activities could be ordered in a sequence that would simultaneously build content and computational science process skills.

As an instructor for Cadre 2 in the summer of 2002, I worked closely with teacher teams to help them use the instructional matrix in their unit planning. While initially intimidated by the matrix, the teachers eagerly began to use it as a discussion tool in the early stages of unit design. One team remarked that they had never considered a real-world problem as motivation for their unit before, but changed the focus of their unit to fit a problem the students would be interested in solving. The additional aspect of the matrix in focusing teachers on the assessment for each piece of their unit served as an additional advantage of the matrix. The major complaint registered by the teacher teams as they began to use the matrix in their planning was that they wished they had seen it sooner, when they were developing ideas for their units.

Use of the instructional matrix among Cadre 2 teachers was ultimately limited by several factors external to the matrix itself. First, the matrix was not developed until less than two months before it was used with Cadre 2 teachers, so teams did not have the benefit of working with the matrix in early unit planning. Second, the design method suggested by the matrix conflicted with two other unit design formats in use by NCSLP. Teachers were encouraged to use a web template to develop their units that was focused more around the computational model rather than the unit itself. A format for lesson plans was also presented to teachers during the summer institute. As a result, teachers struggled to integrate these three formats with their own intentions for unit design, and many chose not to use the matrix and use the web template instead. Finally, several teachers expressed frustration at being asked to consider a new method of unit design after many years of successful classroom practice.

Nevertheless, the process that teachers went through in using or attempting to use the matrix might inform their unit design practice in the future. In feedback from sessions with teachers, one participant wrote, "It really gives structure to a process that can seem uncertain while still grappling with issues of integration of computational science and computer modeling within the classroom." Another teacher described the session working with the matrix as, "The most helpful session I have attended...[It] helped make everything clearer to me." Further evidence of the matrix's ability to help teachers clarify their thoughts while planning were expressed in the following comment: "This was useful in that I was able to imagine what it would be like in the classroom in a teaching role."

How Did Project Teachers React to the Planning and Reflection Tool?

One of the issues discussed in the planning of the Summer Institute was how to give teachers the big picture of what it means to teach students computational science skills. That is, project staff wanted teachers to understand computational science modeling as not just a teaching tool but as a sequenced set of thinking skills that can be applied when using modeling software. The Computational Science Skills Planning and Reflection Matrix in Appendix A was shared with teachers and they were asked to try to use it in designing their units to see if it helped them. As the Summer Institute unfolded, it became clear that teachers were reacting to this tool in different ways. Some saw it as a burden, as just an extra form to fill out and others saw it as a very useful design tool. It appeared that the different reactions were aspects of the different ways in which teachers plan and think about curriculum development.

In a short survey, completed by 49 of the participants at the end of the Summer Institute, we asked a question about their preference for how to integrate computational science thinking into the courses they teach. Their preference selections are shown below.

53%	Build student skills over time by introducing selected short activities (e.g., lessons, assignments) throughout the whole course
24%	Introduce selected examples of computational models as teaching tools to help students better understand certain topics
14%	Implement a problem-based unit in which students go through the steps in a computational science investigation resulting in some kind of presentation and discussion of their results or thinking
8%	Other: ("introduce skills over time and end term with computational science project bringing all physics and computational skills together"; "I think now it is a combo of the three approaches – doing a few modules will give me a better idea")

This is important information for project planners because it indicates that a problem-based, thoughtfully sequenced, student-involved investigative approach to a "replacement unit" as shown in Appendix A may not be the natural inclination of the majority of teachers (only 14% selected this option). Consistent with findings from other projects (Brown & Edelson, 2002), teachers may be more inclined to think in terms of a daily lesson plan approach ("unit" as a loose collection of activities under a given topic).

The survey also asked teachers to select phrases that best represented the strength of the replacement unit they had created. The responses to this item suggest that about a quarter of the teachers saw their unit as a problem-based investigation.

The unit we have developed…

31%	Takes a difficult topic and makes it easier for students to understand through the use of a computational model
24%	Provides a coherent sequence of instructional and assessment activities organized around a real-world problem that students will investigate using a computational model
18%	Presents an interesting computational model for students to explore
10%	Provides a collection of loosely organized activities or lesson plans on a topic that offer a variety of instructional choices
8%	Focuses on teaching students to use a particular technology tool
8%	Other

In a second questionnaire completed by 69 of the teachers in the 2002 Summer Institute during the second week, the teachers provided more specific feedback about the planning tool in Appendix A that they had been asked to use. Responses to two questions are shown below.

Does this tool help you organize instruction and assessment activities for particular student skills? 43 – Yes 15 - No	Does this tool help you plan assessments for your unit? 36 – Yes 17 – No
"Yes" sample comments: It is a defined process where each step is vital. Because the framework is general, any teacher would be able to modify for student skills. I think the framework really helped our group focus on our goals for the unit and helped define a logical sequence of events. Before the framework, our thinking about sequence was confused at best. It's like any tool that helps you see the whole process. The probing questions section helps you stay on track and look at final outcomes. Step by step method ensures topic is covered well enough and in an organized way. It is very specific. Pre-determined probing questions should ensure connections that you want to make are made. You can list various activities, helps you get away from just lecture, almost forces you to think in a different way.	"Yes" sample comments: Helps me focus on assessing more than content. Helps you think about higher-level thought from students. After outlining objectives and probing questions, it's easier to know how to assess. Framework lays out what you want students to be able to do, then you assess. Good reminder of where you came from and where you are going instructionally. Since the steps are so explicit, it's easy to see what you want students to gain and when and how to assess.

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Keeps us on task and in a logical progression of learning. You always have to monitor and adjust but this "road map" is helpful with staying on the right path. The real benefit is the examination and reflection it forces, not the tool. It requires you to organize each day and assess what the student and teacher are doing on a daily basis. It gives me more organizational skills that I lacked. It helps to plan lessons with specific feedback in mind. When working in a group on the design of a unit, it helps because there are so many different ideas coming together.	
"No" sample comments: Nice tool but I have already done methods classes. More helpful for a new teacher. Don't use this kind of planning paperwork – my structuring is more fuzzy. Bit too specific. Too cumbersome, complicated. Too contrived and unwieldy.	"No" sample comments: I plan assessments the same as always. You either cover your objectives and benchmarks or you fail to use your time wisely. I'm so used to traditional assessments and preparing kids for state tests that it is hard to be satisfied with eyeballing a model, etc. This is good for large 2-3 week projects, I do more 1-2 day labs.

The teachers responded to a question that asked them: "In the future, in what ways, if at all, will this tool impact your planning, implementation, and evaluation of instructional units?" The kinds of potential impacts mentioned included:

1) better organized units
2) better sense of the big picture of the unit (of how pieces fit together)
3) increased reflection/motivation to examine unit effectiveness
4) better 'road map' (keep goals and objectives in perspective)
5) better, more efficient lesson plans due to the longer term planning
6) makes sharing units among teachers easier (can visualize the unit in action)
7) particularly useful when planning "real world problem-based units" (not for every unit)

Finally, they were asked if the tool might help them more successfully integrate computational science into the curriculum. Responses to this item suggested some

underlying instructional dilemmas they face over whether the integration of complex investigations into their courses is feasible.

- "Skills in this matrix overlap with national and state standards. Unfortunately, the Massachusetts state test is much more content driven than skill driven. In our school, this has created a pressure to move away from processes and skills as the need to pass the test for graduation becomes a reality".
- "I don't usually teach one topic for two weeks due to curriculum requirements. It would be difficult to allocate the time required on a regular basis."
- "I can use this as a planning tool, to show administrators that there is a need for technology and to allow me to plan better so that I don't skip the technology because there isn't time".
- "Time is always the issue. Computational science must displace something else already in the curriculum".
- "This seems to make the model the heart of a unit instead of a tool to support a unit. My goal is using models not making models".
- "No, the fact is, you don't have enough time to teach what is required already without putting extra content/training of modeling software, on top of it".
- "Only if you could show how several topics could be combined into one unit plan".
- "Takes too long – too many other things to cover, need quick, easy modules already developed."
- "Time is a big issue! We have a state test in biology that students have to pass to receive a diploma. This tool is a help and will be used but it is not something I can spend a lot of time on."
- "By documenting standards met, this tool allows justification of the time spent".
- "I do not want to do the 2 week model so I need to adjust it but the organizational setup for lesson or unit planning is excellent".
- "I think teachers are too concerned with time and covering material, rather than quality and thoroughness. As the information age grows, we need to change and this tool can help".
- "Time and standards to meet are the two biggest factors that limit the development of the curriculum. Unfortunately, since many publishers organize requirements by standards – it is often easier "to go by the book" than it is to develop a modeling unit like this."
- "Yes and no – this tool helps with integration but it doesn't help with time and the amount of content to cover".

Clearly, project planners must consider how to help teachers deal with the perceived need to race through the curriculum using 1-2 day kinds of disconnected activities if they are to be successful in getting teachers to use problem-based investigations in their science classes.

Conclusions

What are the implications of this project's work with teachers on developing "replacement units"? Ideally, the kind of professional development offered by the NCSLP project should become a form of institutionalized support offered in districts if working on the work is going to become an expectation for teachers. Projects like the NCSLP provide opportunities for better understanding how to structure such professional development for curriculum redesign and ongoing reflection at the unit level.

Why "replacement units"? If teachers are encouraged to develop their skills as reflective practitioners, they need to understand the range of instructional segments on which they can reflect in trying to improve the quality of learning opportunities afforded students.

- Perhaps, most traditionally, as in many observation-based teacher evaluation systems, teachers' work has been examined at very discrete, behavioral levels (checklists of behaviors such as wait time).

- Then there are individual lessons. As the Japanese lesson study approach to professional development has shown, the quality of learning opportunities can be successfully examined and continuously improved at the level of individual lessons.

- A new methodology for examining "typical assignments" suggests that having teachers analyze the work they assign has possibilities for improving achievement (Clare et al, 2001).

- Finally, a focus for continuous improvement can be instructional units. From our work, we see several advantages of structured professional development around units. It encourages a big picture understanding of the interaction of content and process skills; it forces attention to the idea and methods of assessment as integrated into a whole; it requires thinking about the efficiency, sequencing and structure of an extended period of instructional time.

There is a role for reflection at all of these levels. They are obviously not mutually exclusive. The data we have presented about the NCSLP and the experiences of others with similar projects seem to converge on some key design elements for professional development around unit redesign and reflection. We present our ideas about what we think project planners should consider and hope that such professional development approaches continue to be tested in more districts and in various subject areas.

1) Prior Knowledge and Skills. Teachers coming into a professional development program to work on units need to develop a common language. There is a need to talk about what a unit is, the different approaches to structuring units, and the depth versus breadth dilemmas that teachers face with state testing mandates. Our data suggest that the majority of teachers think about units as very loose

collections of activities on a topic. Problem-based investigative kinds of units are not the norm. So if increasing teacher use of these kinds of units is a goal for the professional development planners, this goal needs to be communicated. Starting off a professional development effort with having participants examine a "unit in action" (as in Appendix A) might provide a mental model of the goal.

2) Time and resources available. Having content and methodology experts available to teachers is critical as they design units. In the case of this project, scientists who were skilled at the computational modeling software were on–site for the whole two weeks of the summer institute and were consulted with regularly. In another project of which we are aware, local universities are providing the content knowledge support for a two-week summer institute.
3) Planning tools. Having a design tool (as in Appendix A) seems to have the potential to help a group of teachers work more efficiently by allowing them to see the unit as a whole.
4) Implementation feedback. Once the initial unit materials are designed, there needs to be support for piloting the unit in the following school year. Stopping at the development stage and sharing designed but not piloted units allows teachers the option of not implementing their unit. Forming some kind of ongoing "critical friends" group during the implementation year that will allow a group of teachers to bring their unit results to the table for discussion can be very powerful. It sends the message that continuous improvement is valued.
5) Institutionalize the professional development. If located within a district, the process could be continued annually. New teachers could volunteer to participate each year as they felt the need to overhaul or rethink a unit, particularly around building in richer content or deeper levels of thinking skills.

Finally, it seems clear to us that time urgency drives the planning and decision-making of teachers. That is, many feel they have to cover a broad range of topics. Not to cover a concept or topic is to perhaps have students score more poorly on state tests. Thus, running a problem-based, investigation for two weeks, even though they see the benefits for students, raises the issue of non-coverage of other topics. To actually confront these time dilemmas, districts will need to provide support for teachers in making these hard instructional choices.

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APPENDIX A

Computational Science Skills Unit Planning and Reflection Matrix

Example: Human Population Studies Unit

Day	Student Skills	Instruction	Probing Questions	Assessment Process	
				Student Product/Behavior	Feedback
1	1. ***Identify*** real-world problem associated with standards-based concept(s)	Teacher poses problem	• What conditions in a country create a population crisis? • Is it possible for a country to have policy that encourages or discourages population growth? • What are some ways we can find out about the effects of certain variables on populations?	Students answer probing questions posed by teacher in whole-class setting	Based on student responses, teacher provides additional content reading or homework questions if needed to help students develop a fuller understanding of the real-world problem
2-4	2. ***Develop*** background skills and knowledge • Do background research • Develop content understanding of key variables • Conduct investigations (labs) to gather data • Learn to use a modeling tool (e.g., STELLA)	a. Students investigate the effects of environmental conditions on yeast population growth b. Students identify variables affecting population growth in one of six countries using PBS website and other resources c. Students learn STELLA by using tutorial to construct personal budget model	• Where are some places that we can find reliable, numerical data about your country? • What do the different symbols in STELLA mean?	a. Individual reports on yeast population growth b. Individual identification of variables c. Completed personal budget in STELLA	a. Written feedback on report b. Check for accuracy c. Oral comments on model structure and function
5	3. ***Simplify*** real-world problem • Determine applicable principles/laws/procedures • Explain assumptions	Teacher illustrates limitations of modeling and students determine assumptions of their model	• Is it possible to create a model that accurately predicts real-world outcomes? Why or why not? • What are the assumptions we have to make (that is, what do we have to leave out)? • How do we determine what we leave in and what we leave out?	Groups produce assumptions list	Oral comments on parts that are solvable with STELLA
5	4. ***Identify*** variables and interrelationships • Make a diagram or flowchart	Students create simple flowchart showing effects of each variable on population growth	• Which variables will you use? Why did you choose these? • How can you graphically display the relationship between these variables and the population of your country? • What do your graphics mean? • Have you thought about x and y and their effects on your country's population?	Flowchart with narrative explaining relationships	Student response to probing teacher-posed questions
6	5. ***Defend*** the identified relationships and assumptions • Present and defend in groups	Students organize research information and flowcharts into PowerPoint presentation Teacher presents checklist of PowerPoint expectations	• Why did you make the connections in this way?	Groups make PowerPoint presentation of variables and flowchart	Students generate rubric after the presentations to try to capture what they saw as the major differences in quality between the presentations – Groups self-assess based on the rubric developed by the whole class
6	***6. Represent*** relationships in terms of mathematical equations • Use diagrams and relationships to Derive mathematical equations	Teacher uses student work to pull out the math from student flowcharts	• What is the math that underlies your graphical representation? • How would you state these relationships in your own language? • What mathematical operations can we substitute for this language? • What does this math mean? What predictions can we make based upon this math?	Participation by working with flowcharts in groups while teacher explains math Handwritten or Excel equations based upon flowchart	Comprehension check during explanation Yes/no approval of equations based upon comparison with flowchart

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Day	Student Skills	Instruction	Probing Questions	Assessment Process	
				Student Product/Behavior	Feedback
7 8	7. ***Translate*** variables and relationships into computational model: • Translate model into computational process • Review math equations • Run the model • Get results • Explore range of validity • Run check cases	Students build STELLA model using researched variables and mathematical relationships from 6 Students run model, explore results, look for range of validity and run check cases Students switch computers and critique peer models	• Which symbols in STELLA represent your mathematical functions? • What do the results look like? Is that what you expected? Why or why not? • Did you construct the model to reflect your mathematical relationships? • Is there a mistake in your model? How can you fix it? • Does your model work for all numbers, or do some numbers make your model behave erratically? • What happens if you make this number bigger, or this number smaller? Did you expect that result? Why or why not?	Sliders and response of model in "Flight Sim" mode Changes made to model when necessary Peer review of model Demonstrate viability of model by performing check cases and evaluating output	Formative evaluation of model (does it work? do the results look like what was expected? what needs to be changed?) Yes/no approval of changes made to model Monitor participation in peer review Check model output after test cases are performed
9	8. ***Interpret*** findings • Evaluate results • Draw conclusions • Make recommendations	Students use model to explore solutions to the population crisis and formulate conclusions and recommendations	• Were there any surprises? • How confident do you feel about the accuracy of your results? • Is there a better way to do the investigation? • Do we need more data? • What are the sources of error? • What do the graphs mean? • Do your results support the model specified? If not, what would you change? • What recommendations would you give people trying to solve the problem, referencing the model output?	Responses to teacher-posed questions references to the data Letter from group to nation recommending policy	Informal evaluation of student responses Check if students can properly reference data in drawing conclusions Read and respond to policy letter from group to nation
10	9. ***Communicate*** findings • Presentation, letter, essay, etc.	Students prepare letter and presentation	• Why did you choose this solution to the problem? • What data do you have to support this decision? • How well do you think this could work? • What are some loopholes the population of your country might find in your plan? • What are the ideal, long-term results of your policy? • Are there any countries today that use this same policy to control population changes? How successful are they?	PowerPoint presentation referencing original problem, brief research summary, model and model output, and recommendations based upon model output Answers to teacher and student-posed questions	Rubric scoring of recommendations, presentation, and responses to teacher and student-posed questions

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Student Skills	Implementation Challenges	Immediate Changes Made to Implementation	Notes on Student Reaction	Changes for Future Implementation
1. ***Identify*** real-world problem associated with standards-based concept(s)	• Phrasing problem without implying a simple solution	• Making the problem sound more like a mission	• Students seemed initially interested and wanted to know how they were going to solve problem	• Write out the problem as a memo from world leader including specifics for communication of proposed solution
2. ***Develop*** background skills and knowledge • Do background research • Develop content understanding of key variables • Conduct investigations (labs) to gather data • Learn to use a modeling tool (e.g., STELLA)	• Some computers did not have Adobe Acrobat • Focus upon surface research in countries (cars, food) rather than factors influencing population growth • Students using questionable sources to gather research data • Yeast died on third day of laboratory • Students finished tutorial at different rates	• Made hard copies of PBS fact sheets in class set • Increased research requirements to factor out non-essential facts • Encouraged students to compare their research data with that on pbs.org • Tied up lab two days early; used yeast death to facilitate discussion of factors influencing population • Encouraged students who finished early to make additional adjustments to model	• Students were impressed with clock showing population changes • Some dwelled on making fancy presentations rather than content • Difficulty in isolating important information on website • Connection between yeast and humans weak for some students • Frustration with making model incorrectly, confusion over meanings of different symbols and connections	• Clarify research expectations • Make research a homework assignment • Make rules for PowerPoint specific to content and not presentation quality • Try bacteria instead of yeast for growth, or bread mold (easier to keep alive) • Use STELLA more after initial tutorial completion to construct models with similar math to population model
3. ***Simplify*** real-world problem • Determine applicable principles/laws/procedures • Explain assumptions	• Not all students were familiar with exponential growth or had difficulty in transfer from Algebra to Biology • Tendency to encourage students to over-simplify their models	• Performed a simple explanation/review of exponential growth, contrasted an exponential line with linear and polynomial • Backed off from students as they made assumptions	• Many students got lost easily when discussing exponential growth/did not see the point • Some made inaccurate assumptions or removed important factors from their model	• Coordinate with math teachers to find out who has/has not learned about exponential growth • Model assumption-making, actively coach students as they choose challenging but not overly complex or simplified factors for their model
4. ***Identify*** variables and inter-relationships • Make a diagram or flowchart	• Initial difficulty in relating flowchart format and expectations to students	• Made a simple flowchart as a class to model the process	• Students were initially confused by the idea of the flowchart, but seized upon the example in class	• Start with multiple examples before explaining the expectations
5. ***Defend*** the identified relationships and assumptions • Present and defend in groups	• Too informal; students did not feel obligated to participate by asking questions of each other	• Teacher asked a few probing questions of each group	• Students were not confident enough of their relationships to definitively defend their answers	• Formalize defense of relationships and flowcharts by organizing checklist for each student making it necessary to both ask and answer questions; model what a good defense looks like in this context; be more specific about expectations of flowcharts and relationships.
6. ***Represent*** relationships in terms of mathematical equations • Use diagrams and relationships to Derive mathematical equations	• Confused myself (and, consequently, students) when making drawing math from models; tried to generalize too often; selected some flowcharts that did not relate easily to mathematical relationships.	• Selected two good flowcharts and practiced pulling out the math; practiced overnight to increase clarity during presentation to students.	• Students tuned out quickly when they became confused by pulling math out of flowchart • Many students had no interest in understanding the math behind their flowcharts; saying this defeated the purpose of using a program to solve the problems.	• Develop web page or handout interpreting STELLA symbols and relationships into recognizable mathematical functions

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Student Skills	Implementation Challenges	Immediate Changes Made to Implementation	Notes on Student Reaction	Changes for Future Implementation
7. ***Translate*** variables and relationships into computational model: • Translate model into computational process • Review math equations • Run the model • Get results • Explore range of validity • Run check cases	• Tendency to want to make models for students as they struggled • Difficult line between giving students mathematical equations and letting them struggle it out • Students finished at different times	• Backed away, did not allow myself to touch their mouse; rather, talked them through difficult steps • Helped with math on an individualized basis • Stopped class periodically to demonstrate "bells and whistles" to keep advanced students occupied	• Many struggled to make models work, some mathematically and others symbolically (with STELLA) • Even after tedious instruction, many students still did not understand where math came from • Frustrated students too easily gave up with incorrect models	• Have students set their own goals based upon their experience in the previous days • State expectations so that students at many levels can meet them while still challenging themselves
8. ***Interpret*** findings • Evaluate results • Draw conclusions • Make recommendations	• Poorly constructed models led to inaccurate conclusions • Students interpreted results based upon their own experience rather than data gathered during research	• Arranged for before and after-school lab access to assist students in rebuilding inaccurate models • Referred students back to situations in countries to put results into context	• Many students whose models seemed functional in the previous step discovered inaccuracies during interpretation, leading to anger and frustration at "wasted time" • Difficulty in connecting model output to real-world situations	• Do a better job of troubleshooting models before advancing to evaluation phase; increase time for peer review of models; run more formalized test cases
9. ***Communicate*** findings • Presentation, letter, essay, etc.	• Again, many groups made attractive presentations with poor content	• Encouraged subsequent classes to focus on accuracy and content in their presentations	• After initial confusion over slideshow content, students settled into making interesting and thought-provoking recommendations	• Discourage students from making their slideshows "flashy" before content is approved by teacher

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